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ALKALI AGGREGATE REACTIONS, CONCRETE AGGREGATE TESTING & PROBLEM AGGREGATES IN ONTARIO A REVIEW

Engineering
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ALKALI AGGREGATE REACTIONS, CONCRETE AGGREGATE TESTING AND PROBLEM AGGREGATES IN ONTARIO

A REVIEW

PREFACE

This publication is based on lecture notes written for the annual MTC concrete technology courses. The descriptions of the various alkali aggregate reactions and aggregate tests are brief. Interested readers are referred to other, more detailed descriptions and discussions of the various problems. It is hoped that publication of these short notes will help to develop an awareness of aggregate durability problems in Ontario.

ACKNOWLEDGEMENT

The aggregate testing chapter is based on lecture notes written by Grant McCutcheon for the MTC concrete technology courses.

THIS REPORT IS PUBLISHED WITHOUT PREJUDICE AS TO THE APPLICATION OF THE FINDINGS.

CHEMICAL REACTIONS BETWEEN CEMENT ALKALIES AND AGGREGATE

INTRODUCTION

At one time, it was thought that all aggregates were inert. In California in the early 1940's, a reaction between the alkalies (Na_2O & K_2O) in cement and certain aggregates was discovered. This reaction produced highly expansive alkali-silica gel. The expansion of the gel and aggregate under moist conditions caused expansion, cracking and deterioration of concrete.

Cracking of concrete is undesirable for a number of reasons. Cracking reduces the strength of the concrete. Cracks also act as channels for water movement in the concrete leading to an increased degree of saturation and reduced freeze-thaw durability. Increased water movement in the concrete results in more rapid dissolution or leaching of the cement paste (white deposits often seen on concrete surfaces). The actual cracking associated with an alkali-aggregate reaction may not, in itself, be the main reason for concern. The major deterioration is often caused by secondary processes after the reaction has cracked the concrete.

In the past forty years, extensive research has shown that many different rocks can react with alkalies and cause deleterious expansion of concrete. The reactions can be grouped into three broad types (1) alkali carbonate, (2) alkali silica, and (3) alkali silicate. All three of these reactions have been found in Ontario.

In general, the higher the alkali content of the cement, the greater the chance that a reaction and subsequent expansion may take place. Cement with an alkali content of less than 0.6 percent (Na_2O equivalent) is considered low alkali. Generally, the reaction between low alkali cement and aggregate is negligible. In Ontario, low alkali cement is of limited availability, and is expensive.

In recent years, the alkali content of cement has been increasing. This has been caused by changes in the method of cement manufacture. Environmental constraints have resulted in the recycling of alkali enriched flue dust back into the kiln. This has resulted in decreased energy costs because the cement clinker firing temperatures is reduced when the alkali content is raised. Gratten-Bellew *et al* (15) reported that, in the U.S., a changeover to coal fired plants was also causing an increase in alkali content. Type 10 Cement produced in Ontario has an alkali content that ranges, depending on source, from about 0.8 - 1.2 percent (Chojnacki, 2). The alkali content may be as high as 1.35 percent. This is considerably higher than was found twenty years ago. Then, an alkali content of about 0.9 percent was considered high. With this increase in alkali content, there has been an increase in concern about the effect of these high alkali contents on the durability of concrete.

This general increase in alkali content could result in currently non-reactive aggregates becoming unacceptable because of excessive expansion.

Alkali-aggregate reactions are generally slow, and may not be recognized for many years. Recent work has shown that some rocks in Ontario previously thought to be unreactive are, in fact, reactive; see Berard and Lapierre (1) and Dolar-Mantuani, (7, 8, 9). It is quite possible that structures are being built which will have to be replaced prematurely because of excessive expansion caused by alkali-aggregate reactions. It is most important that potentially reactive aggregates are recognized, and are properly investigated before they are used in expensive engineering work. In this publication, the types of reaction that have been recognized in Ontario are briefly described. The areas where these potentially reactive aggregates are found are also outlined.

Petrographic examination, as it is performed by MTC, does not identify potentially reactive aggregate. Petrographic examination only takes physical durability into account. It is hoped to revise the present petrographic system to recognize potentially reactive aggregate. In the meantime, everyone concerned with concrete construction should be aware of the potential for alkali-aggregate reactions.

It takes about a year to properly investigate the potential alkali reactivity of an aggregate. This factor should be remembered when structures are to be built in areas where potentially reactive aggregates are found.

ALKALI-CARBONATE REACTION

Rocks of the Gull River Formation (Lake Ontario Basin) and the Ottawa Limestone (Ottawa-St. Lawrence Lowlands) are alkali reactive. The general area of occurence of these rocks is shown in Figure 1. Only certain beds are reactive. These are beds of fine grained dolomitic limestone with a significant clay mineral content. These beds are generally found in the lower and middle members of the Gull River Formation and the lower beds of the Ottawa limestone known as the Pamelia Formation. The rocks are perfectly durable when used as building stone or in asphalt. When they are used in Portland cement concrete, they expand and cause cracking and deterioration of the concrete (Figures 2 & 3). In a recent example in Lancaster, concrete sidewalks expanded up to 1.2 percent after 3 years.

The cause of the expansion is not properly understood at present. Gillott (14) has suggested the dedolomitization of the dolomite crystals opens channels allowing moisture to be adsorbed on previously dry clay surfaces. The swelling caused by water adsorption causes irreversible expansion of the rock and the subsequent expansion and cracking of concrete. For a detailed discussion of this reaction and the possible mechanism causing it, see Walker (36).

If a quarry is suspected to contain alkali-carbonate reactive rock, a number of different techniques may be used to identify the reactive beds and those beds that may be safely used in concrete. The quarry face is sampled at about 0.3m intervals and examined microscopically to see if the texture characteristic of reactive rocks is present (Figure 5). The rock cylinder expansion test (ASTM C586) is also conducted. Rock cylinders (35x9mm) are prepared from the hand specimens used for the microscopic examination. These are stored in sodium hydroxide solution. Expansion in excess of 0.1% after 4 weeks or 0.2% after 16 weeks usually indicates alkali-carbonate reactivity (See Figure 6).

When the non-reactive beds have been identified and a suitable working face established, aggregate is tested in the concrete prism expansion test (CSA A23.2-14A). Concrete prisms are made with the suspect aggregate and normal Portland cement. These prisms are stored in a moist room for a period of at least one year and the expansion measured. Most concrete used by MTC is in a moist environment and exposed to de-icing salts. Aggregate for use in this environment is tested with normal Portland cement fortified by the addition of NaOH to give a cement alkali content of 1.25% Na_2O equivalent. An expansion of the concrete, of greater than 0.025% at 1 year is considered excessive (See Figure 4). If the prisms show excessive expansion, petrographic examination may be conducted to check for the development of reaction rims (Figure 7). The detection of these rims on crushed stone generally confirms the presence of a reaction. The absence of reaction rims, however, does not necessarily demonstrate that a reaction is not taking place.

Waiting a year for approval to use an aggregate is regarded by many engineers as unreasonable. As a result, a quick chemical test has been developed in Ontario (MTC LS-615). A sample of aggregate is submitted for chemical analysis. The CaO:MgO ratio and alumina (Al_2O_3) content is determined. These results are plotted on a graph (Figure 8). Depending on the area of the graph in which the results plot, the sample may either be accepted without further testing or cannot be accepted until the concrete prism expansion test is conducted. In this way, the majority of carbonate rocks can be approved relatively quickly.

When alkali-carbonate reactive rock has been identified, the solution is to exclude the reactive beds from use by selective quarrying. Alternatively, the reactive rocks can be diluted with non-reactive aggregates. It is possible to use a low alkali cement to slow the reaction, but migration of solutions within the concrete will result in areas of increased alkali content. De-icing salt (NaCl) will also add alkalies to the concrete, and increase the rate of reaction (See Smith, 31)

Papers by Smith (31, 32) and Rogers (29) contain a summary of this Ministry's experience with this problem. A paper by Swenson and Gillott (35) is a review of research conducted by the National Research Council on the reaction in the Kingston area. A paper by Dolar-Mantuani (9) outlined those formations that are likely to be reactive, and described the mechanism of reaction. Papers by Ryell et al (30), Emery and Drysdale (13), and Koniuszy and Rogers (23) described the procedures used in investigations of alkali-carbonate reactivity.

ALKALI-SILICA REACTION

All forms of amorphous and microcrystalline silica are potentially alkali-silica reactive. The main alkali-silica reactive minerals found in Ontario are chalcedony and optically strained quartz. Cherts, cherty limestones, sandstones and granites from Ontario have all been found to be alkali-silica reactive. Artificial glass may also be alkali-silica reactive. Reaction between the silica and alkalies from the cement results in the formation of alkali-silica gel. The formation and expansion of this gel in the presence of water results in the generation of internal stress. Subsequent expansion may cause cracking and disruption of concrete. For a detailed discussion on the nature and mechanism of this reaction, see a paper by Diamond (3).

Concrete aggregates should be subjected to detailed petrographic examination. This may often require study under a polarizing microscope to look for chalcedony in cherts and cherty limestones or highly strained quartz in sandstones and granites. The mortar bar test (ASTM C227) is employed with aggregate suspected to be alkali-silica reactive (Figure 9). MTC practice is to test the aggregate with normal Portland cement fortified by the addition of NaOH to give a cement alkali content of 1.25% Na_2O equivalent. An expansion of greater than 0.05% at three months or 0.1% at six months is considered excessive. The quick chemical test (ASTM C289) is not practical when the aggregate contains significant amounts of carbonate minerals. In Northern Ontario, where igneous gravels are contaminated with small amounts of chert, with little or no carbonate, this test may be more useful.

Sandstones and granites are slowly alkali-silica reactive, and may give unreliable tests results. With these rock types, acceptance should be based on past field performance and petrographic examination. For instance, aggregates containing large proportions of sandstone or granite, such as obtained in quarrying operations, should not be used unless there are many years of good field performance of concrete exposed under similar conditions to those intended. Alternatively, a thorough petrographic examination and exhaustive testing may show the aggregate to be innocuous.

Once an alkali-silica reactive rock has been identified, the use of either a low alkali cement or a pozzolan to replace some of the cement could be investigated. It would, however, generally be preferable not to use reactive rocks in concrete. The risk of using a reactive or a potentially reactive concrete aggregate is usually too great in view of the relatively small cost of aggregate compared to the value of the structure in which it is used.

Chert

Chert is found in gravel pits and quarries throughout most of Southwestern Ontario and in parts of Northern Ontario (see Figures 34 and 35). These cherts of Palaeozoic age contain silica in three forms: ultrafine microcrystalline quartz (opal-like), chalcedony, and coarse microcrystalline quartz. The first two forms are alkali-silica reactive. The coarse microcrystalline variety appears to be less reactive.

Chert, in addition to being alkali-silica reactive, may also have poor resistance to freezing and thawing, depending on its type. Leached, porous chert is especially susceptible to frost action, and commonly causes popouts on concrete surfaces and, when abundant, may cause severe deterioration of concrete. Unleached chert and cherty carbonate may also cause popouts by a combiration of alkali-silica reaction and frost action. Incidently, both types of chert also cause popouts in asphalt pavement surfaces. Leached chert absorbs the asphalt cement, weakening the bond with the matrix. The particle is subsequently removed from the surface by frost action (Rogers, 28). Unleached chert has a poor bond with asphalt cement, and is easily lost from the surface. Cherts are easily recognized in petrographic examination, and the quantity permitted in any aggregate is severely limited. A study by MTC of the cherts of Southwestern Ontario is that of Ingham and Dunikowska-Koniuszy (22).

On Highways 11 and 101 between Long Lac and Timmins, and also in the vicinity of Sioux Lookout (Figure 10), many structures are deteriorating because of a combination of frost action and alkali-silica reactions. These structures were built in the late 1930's and 1940's using local gravels which contain chert from the Palaeozoic rocks of the James Bay Lowlands. In the early 1950's, the detrimental nature of chert was recognized. Chert-free aggregate has been used for concrete in most structures built since then. There has, as a result, been a considerable improvement in durability and a reduction in maintenance and repair costs.

On Highway 17 between Nipigon and White River, some of the concrete structures, built in the 1950's, show minor cracking caused by very small amounts of chert (less than 1 percent) found in the local sands. A C.N.R. bridge east of Thunder Bay has also been found to be deteriorating because of the use of alkali-silica reactive sand in repairs to the structure in the late 1950's. The sand contained small amounts of Palaeozoic chert probably imported from a gravel pit near Nipigon.

In the Windsor and Sarnia area, several concrete structures and a pavement are deteriorating because of an alkali-silica reaction. These structures and pavement were built in the early 1970's with a sand imported from the west coast of Michigan. This sand contained about 5% leached chert. This was sufficient to cause extensive cracking of concrete structures and disruption and deterioration of the concrete pavement after 10 years (Figures 11, 12 and 13).

The bridge over the Englehart River on Hwy. 66, west of Kirkland Lake was built in 1969. The coarse aggregate for the concrete was waste rock from the Adams Iron Mine. The aggregate was composed of some cherty iron formation of Precambrian age. The chert was a coarse mosaic of microcrystalline quartz with abundant fluid inclusions and disseminated magnetite. This structure had its bridge deck extensively repaired within six years. The remainder of the structure shows extensive cracking caused by an alkali-silica reaction between the chert and alkalies from the cement paste (Figure 14).

Cherty Limestone

Recent work by MTC and the National Research Council has shown that some slightly cherty Palaeozoic limestones in the Ottawa area are alkali-silica reactive. The work is incomplete, and much study

remains to be done. The reactive rock is found in quarries near Ottawa in the Bobcaygeon Formation, also known as the Rockland Member of Lower Trenton age. The reactive aggregate contains small amounts of black chert (3% or less), as well as microscopic chalcedony in the limestone. The reactive beds are found in the same sequence, but stratigraphically above the alkali-carbonate reactive rocks described earlier. Testing of aggregate from two Ottawa quarries has shown that mortar bars made with 1.25% Na_2O equivalent alkalies expand excessively (Figure 9).

At present, those quarries that contain beds of this cherty limestone produce satisfactory concrete aggregates by selective quarrying. In one case the upper bench is alkali-reactive, in another, the upper bench is the only non-reactive rock in the quarry. In these operations care is required to ensure that concrete stone does not become contaminated with alkali-silica reactive rock.

About twenty-five structures have been built with these reactive aggregates. Those parts of the structures exposed to moisture and de-icing salt (NaCl) show pattern cracking after about ten years (Figures 15 and 16). Those parts not exposed to direct moisture show little or no cracking at present. The initial alkali content of the cement was about 0.9 to 1.1% Na_2O equivalent (3.0-3.9 Na_2O kg/m^3). MTC experience is that the type and amount of cracking shown by these structures will result in increased maintenance and repair costs at an age of 30 to 40 years compared with structures not exhibiting this cracking.

In Montreal and Three Rivers areas, work by J. Berard (personal communication, 1982) has shown that limestones of Lower Trenton age, similar to those found in Ottawa, are alkali-silica reactive.

A structure in Lindsay, Ontario, built in 1954, has recently been found to be deteriorating because of an alkali-silica reaction. The reactive aggregate is a quarried limestone with small amounts of chalcedony. The microscopic appearance of the rock and the nature of the reaction appears identical to that found in the Ottawa area. The source of the aggregate has yet to be found.

The reaction of these cherty limestones is treacherous because the reaction is relatively slow, and may go unrecognized for some years. Furthermore, the nature of the deterioration is such that it can often be assigned to other causes such as frost action or distress caused by rusting of reinforcing steel. Microscopic examination of suspect concrete is necessary to detect the presence of alkali-silica gel in order to determine the cause of distress.

Sandstone

The Potsdam sandstone has been found to be alkali-silica reactive. Berard and Lapierre (1) have described this reaction which has caused deterioration of several structures southwest of Montreal (see Figure 17). The Potsdam sandstone is found in both pits and quarries in the general area outlined in Figure 33 by Sandstone (No. 4). A bridge on Highway 2, west of Kingston, contains a small amount of this sandstone which shows characteristic reaction rims. The quantity of sandstone in the concrete was too small to have caused disruption of the concrete (Figure 18).

In the area north of Lake Huron, sandstones and feldspathic sandstones of the middle Precambrian, Huronian Supergroup have been found to be slowly alkali-silica reactive (Figure 19 and 20). Argillites and greywackes of this same group of rocks are also alkali-silicate reactive (see next section). The general area of occurrence of these rocks is the same as that of the argillite and greywacke shown in Figure 34. These rocks may be found in gravel pits throughout this area. The reactivity of these sandstones appears to be related to the high degree of strain shown by the quartz under cross polarized light.

Granite

Recent study of two bridges in the City of Toronto has shown an alkali-silica reaction with crushed granite from two quarry sources. The structures were built shortly before 1918. The granite was used to give a decorative exposed aggregate finish to the parapets. The remainder of the structures were built using local gravel, and are in excellent condition. A reaction has taken place between highly strained quartz in the granite and alkalies from the cement. This slow reaction has been aggravated by exposure to sodium chloride solutions splashed onto the parapets during the winter. Pattern cracking (Figure 21) is common. Examination of concrete cores showed that the pattern cracking only penetrated the concrete to a depth of 5 cm. Below this, the concrete was extensively microfractured, and contained deposits of alkali-silica gel lining microfracture surfaces and filling air voids (Figure 22).

Expansion of the concrete has caused bending of some elements and severe cracking. This expansion was recognized at some time in the past, and drilling conducted in some joint areas to provide additional expansion space. These joints are now closing due to continued expansion. Other bridges built using the same parapet design at about the same time, but using dolomitic marble as the coarse aggregate are undamaged and in excellent condition. The granite used in the two structures is similar petrographically to granites of Grenville age from Eastern Ontario and Quebec.

Petrographic examination of concrete from old bridges in Parry Sound and Kingston (Figure 23) has shown dark, clarified rims on the periphery of granite aggregate particles. This is normally taken as indicative of a reaction between aggregate and the cement. In both cases, the quantity of granite in the concrete was small, and had not adversely affected the integrity of the structure.

Glass

Man-made glass may also be alkali-silica reactive. Contamination of concrete aggregate sources or stockpiles with broken bottles should be avoided. Two cases are known in Ontario, of damage to concrete caused by inclusion of artificial glass in concrete aggregate. In one case, glass fragments found in sand from the Niagara River caused small popouts on the surface of a concrete slab. This slab was indoors and was covered with vinyl tiles. The cement alkalies were about 0.7% Na_2O equivalent. The popouts occurred within about 2 1/2 years (Woda and Hussel, 37). In the other example, artificial glass is reported to have been used in decorative, exposed aggregate concrete panels.

ALKALI-SILICATE REACTION

Argillites and greywackes of the Huronian Supergroup are alkali-reactive (Dolar-Mantuani, 7). These metamorphosed sedimentary rocks are found in Northern Ontario from Blind River through Sudbury to New Liskeard (Figures 34 and 35). Gravel deposits in this area and to the south (vicinity of French River) may contain these rocks together with alkali-silica reactive sandstones of the same age described above. These rocks react with alkalies from cement paste to cause expansion and cracking of concrete (Figures 24 and 26).

A field survey of highway structures in the Sudbury area has shown that twenty six structures are affected by this reaction. They range in age from four to forty-six years (Figure 27 and 28). The coarse aggregate was gravel from the airport area or similar gravels. The percentage of reactive rock types (argillite, greywacke, sandstone and/or arkose) was between about 65 and 90 percent. Pattern cracking, reaction rims on the coarse aggregate and alkali-silica gel formation was common in all elements exposed to moisture and de-icing salt (NaCl). Three older structures have been replaced (Figure 27) as a result of deterioration of concrete promoted by this alkali-aggregate reaction. Many of the others require or will require extensive repairs. The alkali content of the cement used in 16 structures built since 1967 varied from about 0.8 to 1.2% Na_2O equivalent. Many sidewalks built in the past fifteen years show pattern cracking. From the results of this survey it is concluded that some of the gravels from the Sudbury area are alkali reactive and cause premature deterioration of concrete.

In the New Liskeard area, the content of reactive rock types in the gravels is lower (40-55%), but there is a higher proportion of argillite and greywacke compared with the sandstone and arkose. Also in this area the sands contain trace amounts of alkali-silica reactive Palaeozoic chert. This makes it difficult to judge the damage caused by the alkali-silicate reaction alone. The Lady Evelyn Lake Dam built in 1925 was replaced in 1972 because of damage caused by this reaction (Dolar-Mantuani, 7), see Figures 24 and 26. There are at least four highway structures in this area that show pattern cracking and associated deterioration due to the reaction between argillite and greywacke with cement alkalies (Figure 29).

The reaction of these rocks with alkalies is generally slow, and is not properly understood. Dolar-Mantuani (7) showed that these rocks slowly expand in the rock cylinder expansion test (ASTM C586) normally used for alkali-carbonate reactive rocks. They also caused expansion of mortar bars (ASTM C227) with the generation of alkali-silica gel. Gratten-Bellew (17) found that expansivity was related to porosity and the percentage of microcrystalline material present in the rock. The greater the amount of microcrystalline material, the greater the expansion. Argillites, which are very fine grained, are probably deleteriously expansive; the greywackes, which are coarser, are less expansive. He concluded that expansion of concrete was mainly due to expansion of the individual rocks although, in one case, expansion was partly attributed to the formation of alkali-silica gel.

The expansion of these argillites and greywackes in concrete is termed the alkali-silicate reaction. While there are similarities with the alkali-silica reaction, the expansion of individual rock particles suggests absorption of water on previously 'dry' alumino-

silicate surfaces in the microcrystalline portion of the rock. Furthermore, the results of the diagnostic tests used for detecting the alkali-silica reaction may be misleading. Both the quick chemical test (ASTM C289) and the mortar bar test (ASTM C227) may give unreliable results (Gratten-Bellew, 17).

Current MTC practice, in the area of Ontario where these rocks are found, is to conduct petrographic examination of the aggregate. If the quantity of potentially reactive rock types (argillite, greywacke, sandstone and/or arkose) is less than about 15%, the aggregate may be used in concrete without further testing. If there is greater than 15% reactive particles, then the aggregate should not be used until testing shows it to be satisfactory. At the present time, a high temperature concrete prism expansion test (CSA A23.2-14A) is the best method of evaluation. The prisms are stored in a 100 percent humidity atmosphere at 38°C rather than the 23°C normally used for the alkali-carbonate reaction. Unfortunately, reliable maximum expansion values to separate deleterious from satisfactory aggregates have not been developed. Preliminary work suggests an expansion in excess of 0.04% after one year indicates that the aggregate is likely to cause cracking in highway structures.

Work by Ontario Hydro (34) has shown that the use of low alkali cement or fly ash replacement of the cement considerably reduces expansion due to this reaction. At the Lower Notch Dam on the Montreal River, 20% fly ash replacement was used successfully to prevent cracking of concrete containing argillite and greywacke. At present, MTC prefers not to use either low alkali cement or fly ash substitution as a corrective measure. This is due to the difficulties of ensuring that low alkali cement is actually in the concrete delivered on the construction site and because of the variable air-entraining characteristics of fly ash.

APPROVAL OF CONCRETE AGGREGATES

Clearly, the alkali-reactivity testing of concrete aggregates is time consuming and calls for specialized equipment. Some way had to be found to rapidly approve concrete aggregates. The approach taken by MTC has been to publish a list of approved concrete aggregate sources in each region of Ontario (Figure 30). For a source to be included on this list it has to either have passed all applicable tests or to have a good record of past field performance in highway structures. The aggregate source is placed on the list together with any restrictions. For instance, in quarries, the approved level is specified since other levels may be alkali-reactive.

The concrete aggregates sources list is used as part of the contract documents. The concrete aggregates must come from the approved sources. It is the job of the construction staff to ensure that the aggregates actually delivered on the job site are from these sources. As a further check, samples are taken once or twice a year from the various deposits and tested to confirm that they meet the requirements.

A word of caution. It is the responsibility of individuals who use MTC approved concrete aggregate sources to ensure that the aggregate actually meets the requirements. Just because a source is shown on the list does not mean that the aggregate in any one stockpile is acceptable.

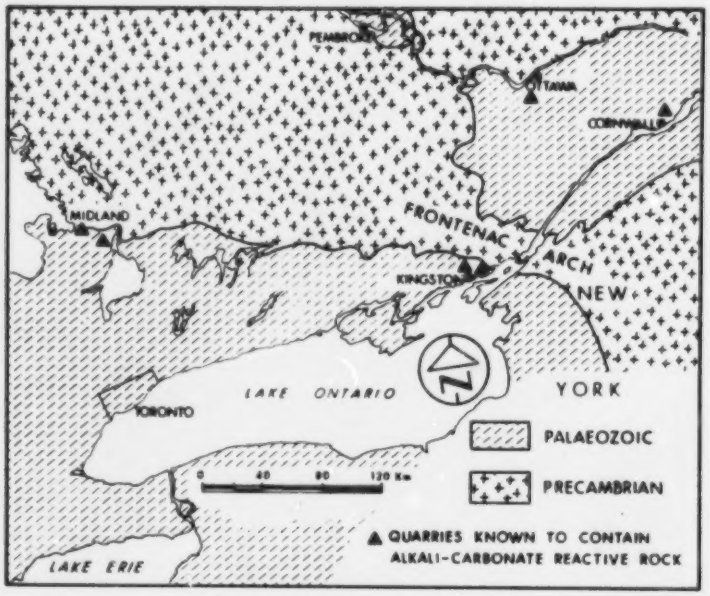

Figure 1 Location of known sources of alkali-carbonate reactive dolomitic limestone in Ontario.

Figure 2

Alkali carbonate reaction Lancaster, reactive concrete (upper part of photo) has moved 9 cm to the right compared with non reactive concrete (lower part of photo). Expansion was measured as 1.2 percent in 3 years.

Figure 3 Alkali carbonate reaction, Lancaster. Expansion of sidewalk from left to right has pushed curb about 6 cm into pavement, causing shoving of the asphalt.

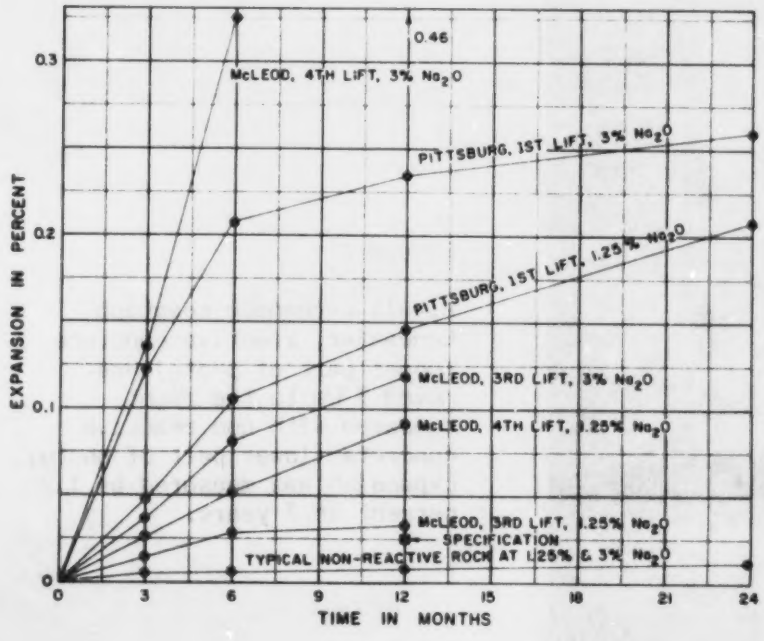

Figure 4

Concrete prism expansion data (CSA A23.2 - 14A) for some typical Alkali-carbonate reactive dolomitic limestones.

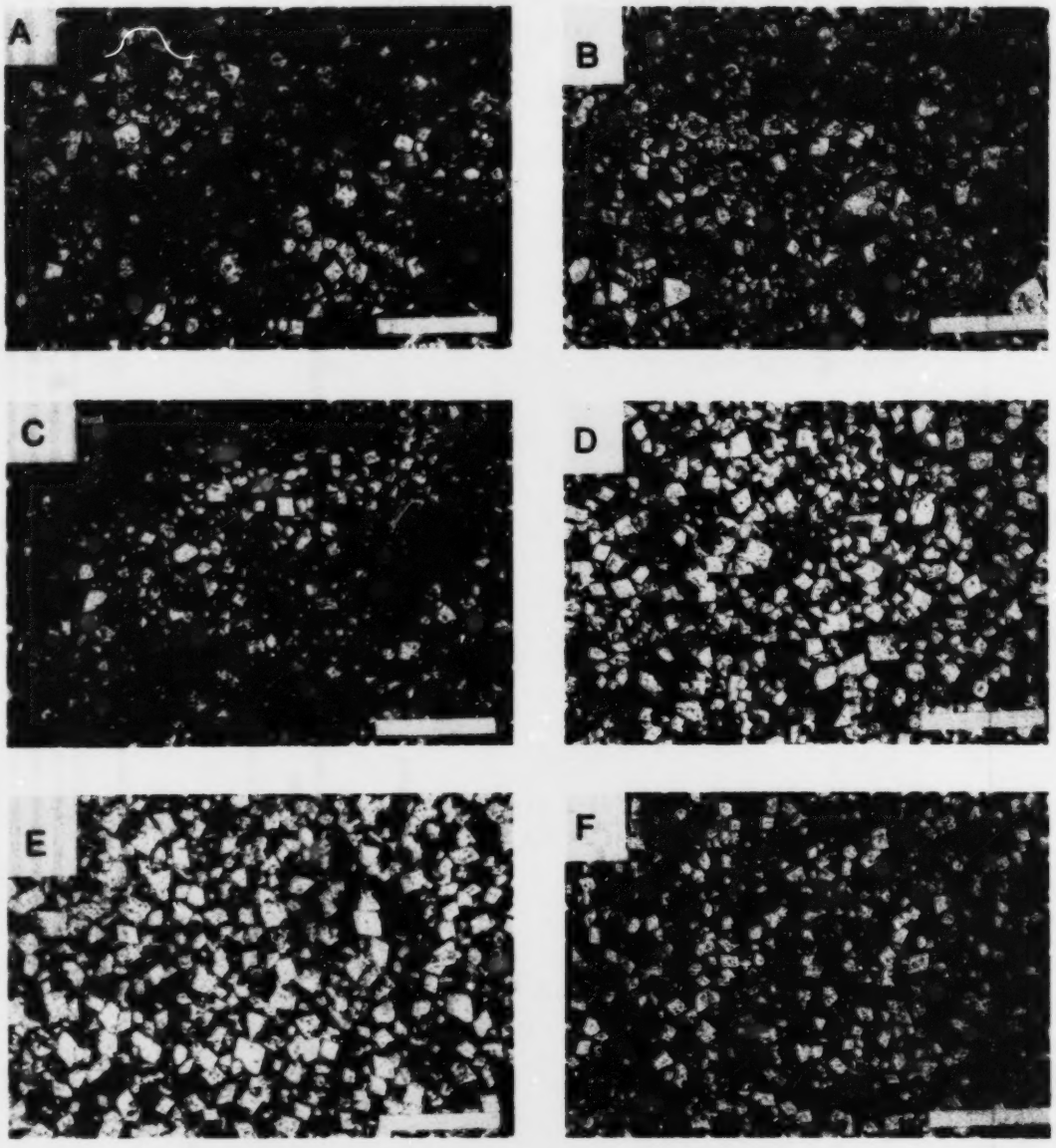

Figure 5 Microphotographs of thin sections of alkali-carbonate reactive dolomitic limestones. Scale bar represents 0.25 mm. A. McLeod Quarry, Cornwall; B. Cooke Quarry, Waubaushene; C. Pittsburgh Quarry, Kingston; D. Uhthoff Quarry, Orillia, U1 bed; E. Uhthoff Quarry, UB bed; and F. Uhthoff Quarry, U1 bed.

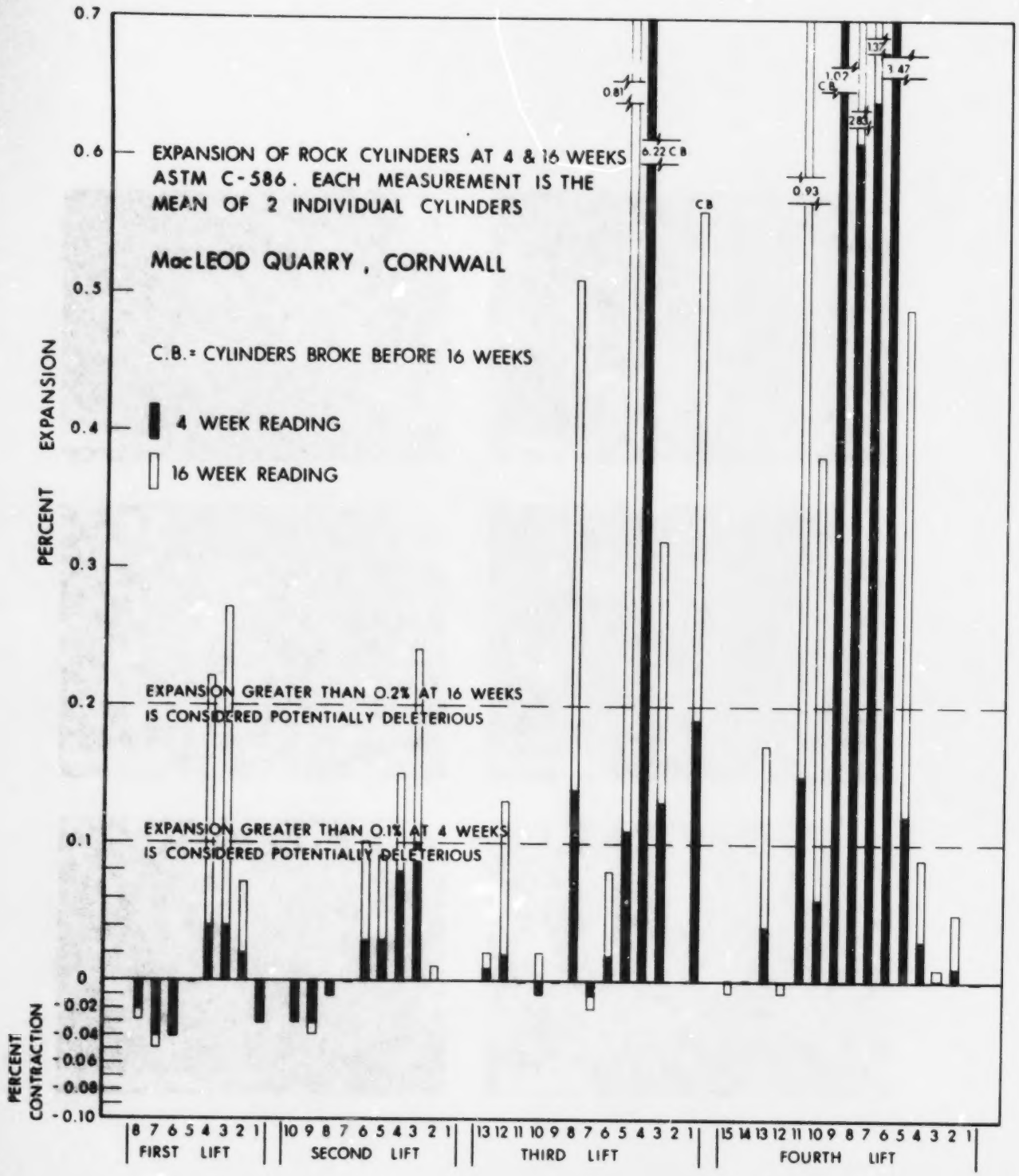

Figure 6 The rock cylinder expansion test can be used to identify alkali-carbonate reactive beds. In this case, the first and second lifts are non-reactive, the third and fourth lifts are reactive.

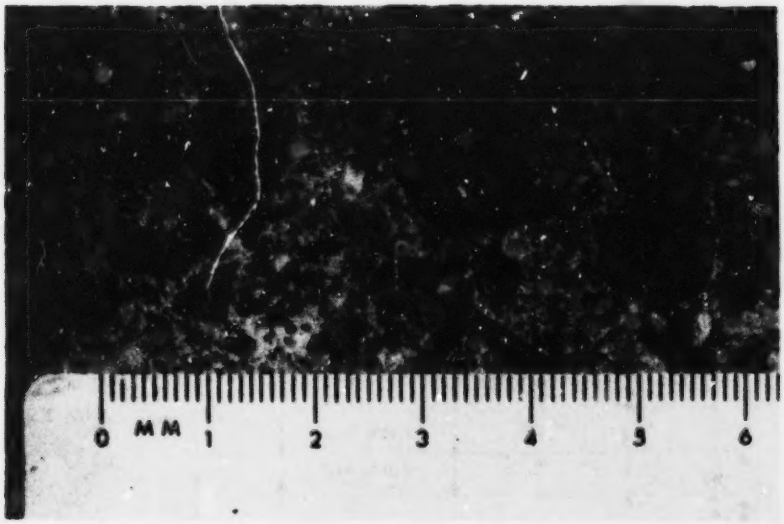

Figure 7 Reaction rims on crushed carbonate coarse aggregate due to alkali carbonate reaction.

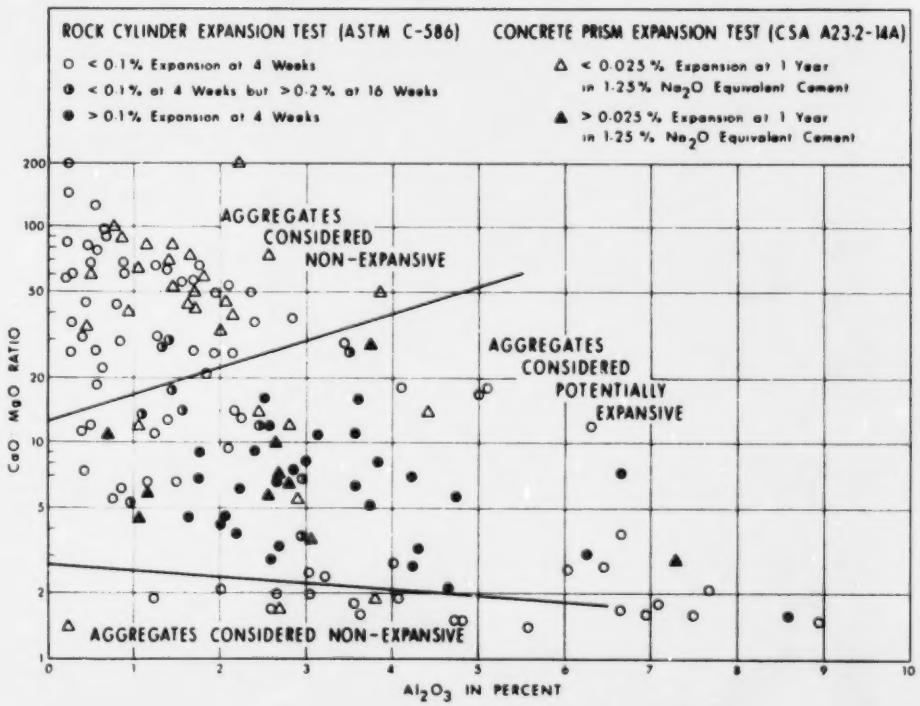

Figure 8 Graph used for determining the potential expansivity of quarried carbonate rocks in the chemical test used by MTC (MTC LS-615).

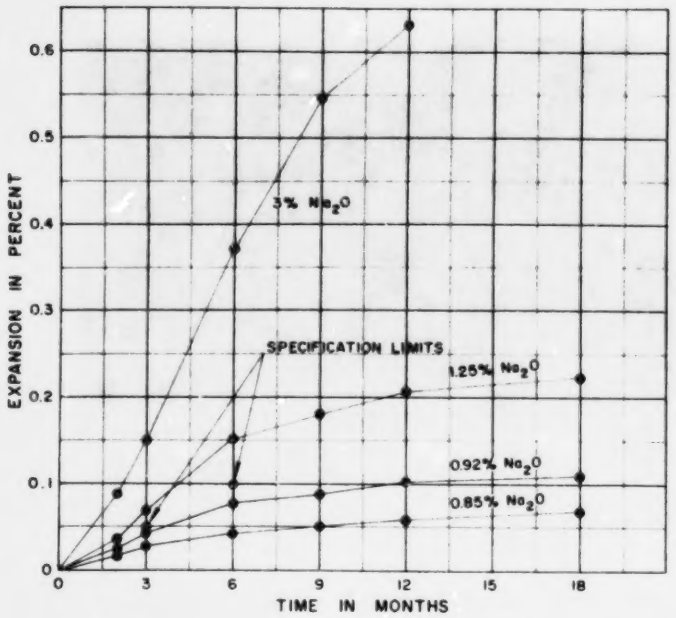

Figure 9

Mortar bar expansion Test data (ASTM C-227) for typical alkali-silica reactive cherty limestone from the Ottawa area.

Figure 10

Alkali-silica reaction, Frog Rapids Bridge, Hwy. 72 near Sioux Lookout. This structure was built in 1938 using a local gravel containing small amounts of leached Palaeozoic chert.

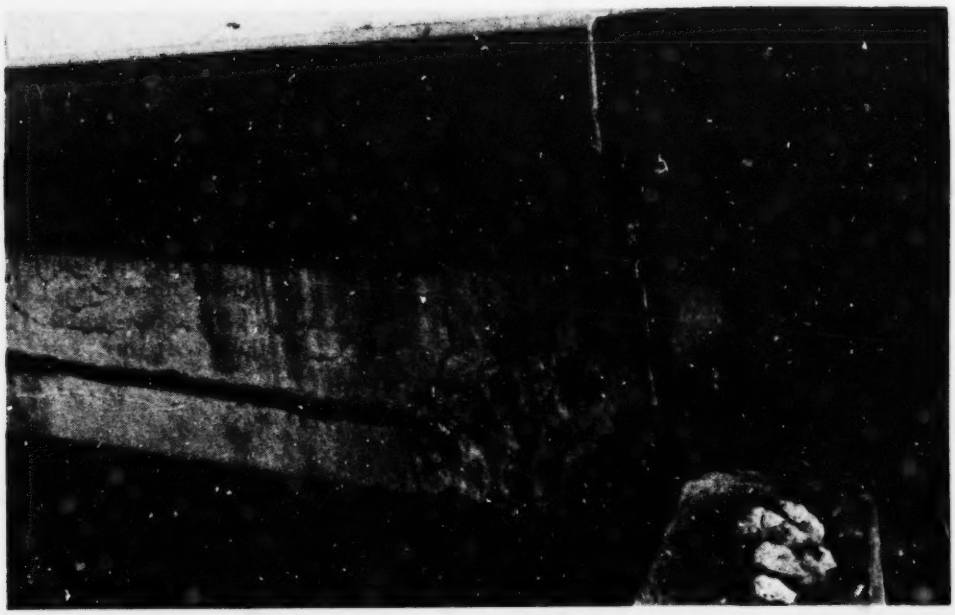

Figure 11 Alkali-silica reaction, Dougall Avenue Structure, E.C. Row Expressway, Windsor. Note cracking and associated failure in joint area caused by about 5% leached chert in fine aggregate, 12 years old.

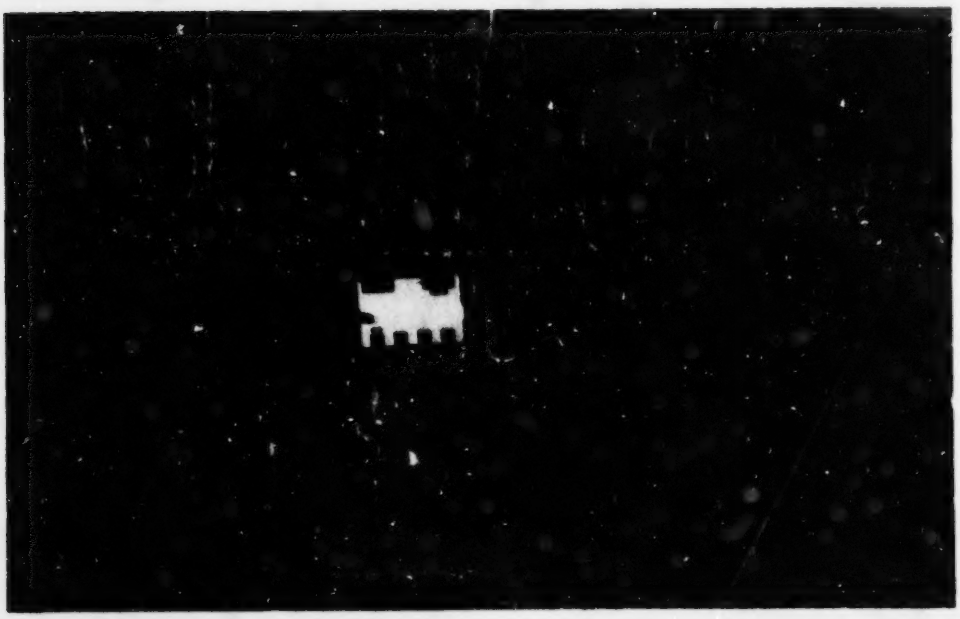

Figure 12 Alkali-silica reaction, E.C. Row Expressway, Windsor. Note cracking and failure after 12 years. Also, note relative displacement of joints due to expansion caused by about 5% leached chert in fine aggregate.

Figure 13

Alkali-silica reaction, E.C. Row Expressway, Windsor. Cut and polished surface of pavement concrete shows air void filled with alkali-silica gel adjacent to leached chert particle (c) in fine aggregate. 3x magnification.

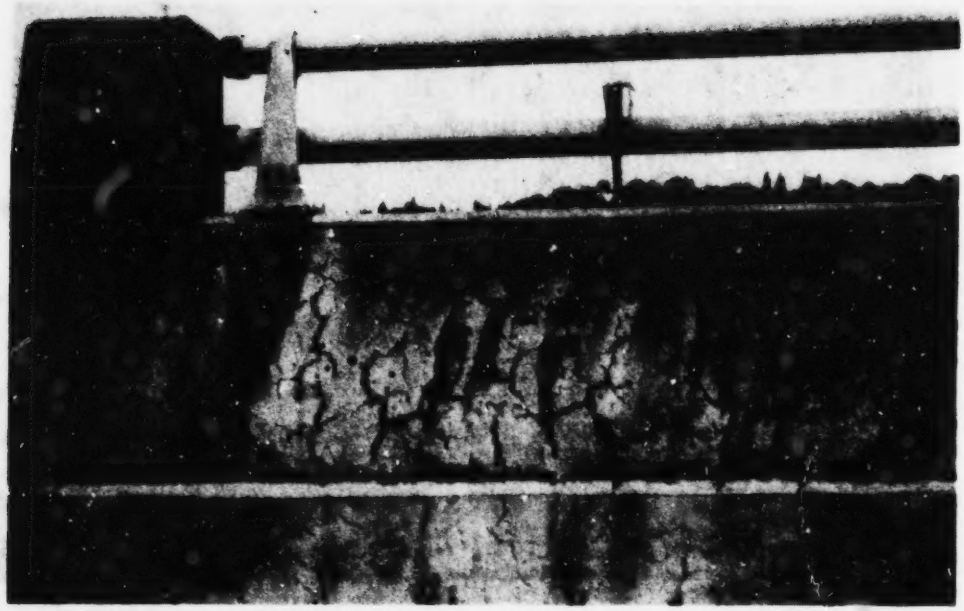

Figure 14 Alkali-silica reaction, Englehart River Bridge, Hwy. 66, built 1969. Cracking is due to a reaction with Precambrian chert which was waste rock from a local mine.

Figure 15 Alkali-silica reaction, Hwy. 417, eastbound, over Russel Road, near Ottawa. Built 1969, appearance after 16 years. Reactive coarse aggregate contained less than 3% chart. Limestone of the Bobcaygeon Formation.

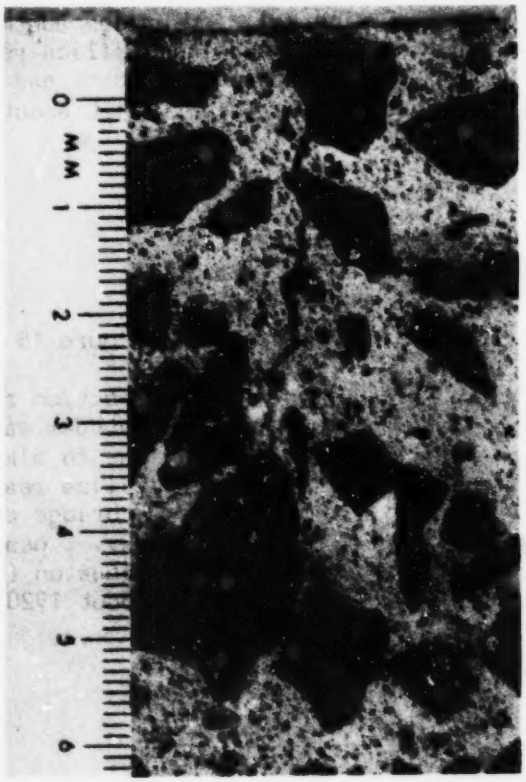

Figure 16

Alkali-silica reaction, Hwy. 417, eastbound, over Bear Brook. Built 1969. Cut and polished surface of concrete from from curb shows pattern cracking which penetrates about 4 cm. Note gel filled cracks in coarse aggregate particle. Concrete below a depth of about 5 cm is extensively microfractured. 16 years old. Coarse aggregate is limestone of the Bobcaygeon Formation.

Figure 17 Map or pattern cracking of wing wall and bridge abutment, Valleyfield, P.Q. This is caused by alkali-silica reaction with Potsdam sandstone. Note leaching of cement and spalling due to compression at construction joint (built about 1930).

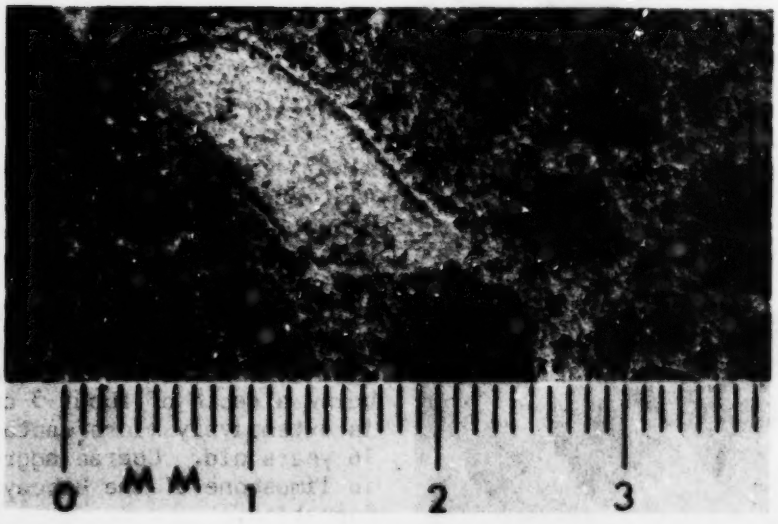

Figure 18

Reaction rim on Potsdam sandstone due to alkali-silica reaction - bridge deck on Hwy. 2 near Kingston (built about 1920).

Figure 19

Alkali-silica and alkali-silicate reaction. Serpent River Bridge, Hwy. 17. This structure, built in 1938, shows extensive cracking and deterioration. Initial cracking due to reactions has been aggravated by frost action and leaching of cement.

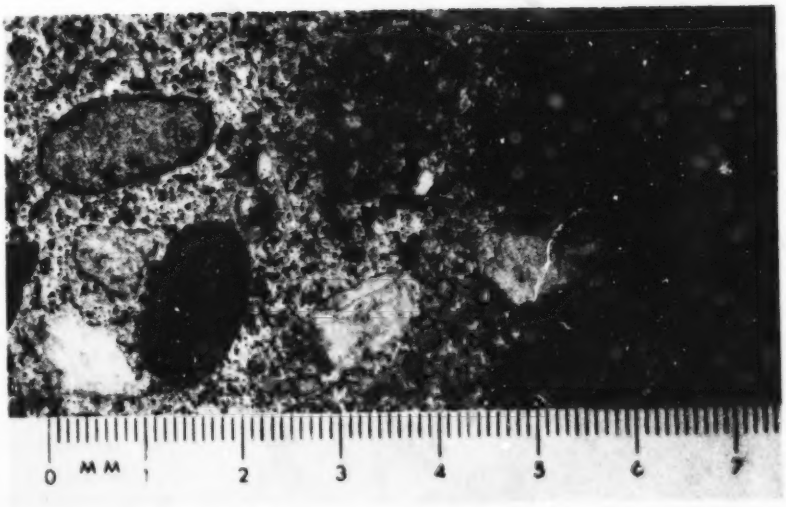

Figure 20 Serpent River Bridge. Cut and polished concrete surface shows dark, clarified 'reaction' rims on alkali-silica reactive sandstones. A dark particle of greywacke in upper right is cracked due to the alkali-silicate reaction.

Figure 21 Alkali-silica reaction, Prince Edward Viaduct, Toronto, built before 1918. Cracking is due to a reaction with granite used as coarse aggregate for a decorative finish.

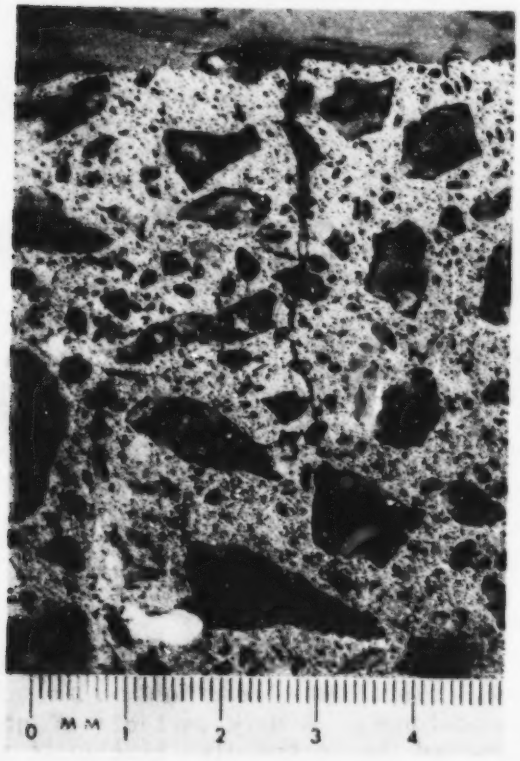

Figure 22

Alkali-silica reaction, Rosedale Ravine, Toronto, built before 1918. Note dark, clarified rims on some granite particles and air void filled with white alkali-silica gel (bottom left). Crack from surface only penetrates about 5 mm into concrete, but note microfractures in the lower part of concrete.

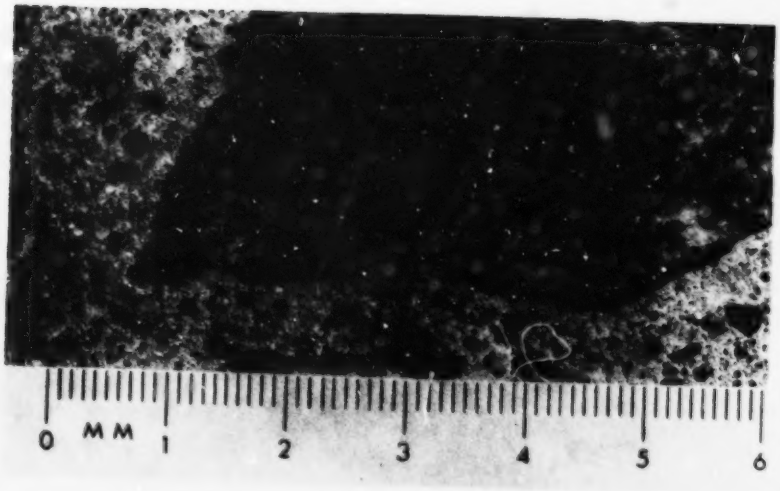

Figure 23 Alkali-silica reaction, Millhaven Creek Bridge, Hwy. 2, near Kingston, built 1920. Note dark clarified rim on this foliated granite indicative of a reaction.

Figure 24

Alkali-silicate reaction. Lady Evelyn Lake Dam, built 1925, replaced 1972. Cracking and displacement (see major crack at top centre) is due to the use of argillite and greywacke in the coarse aggregate and alkali-silica reactive palaeozoic chert in the fine aggregate.

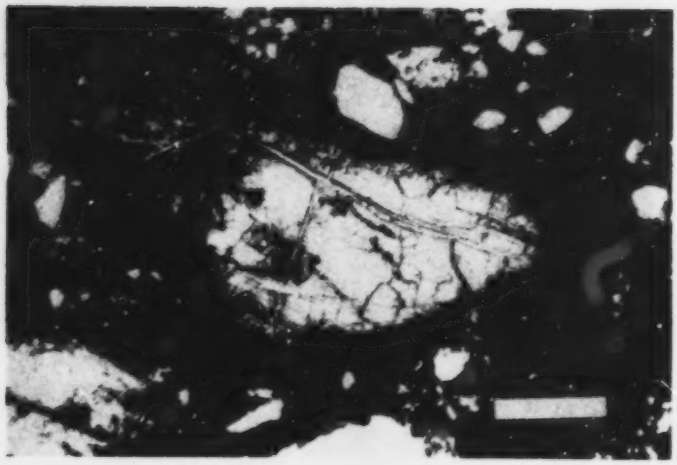

Figure 25 Palaeozoic chert particle in fine aggregate of Lady Evelyn Lake Dam (1925). Alkali-silica gel has replaced much of the original chert. Note cracking associated with this gel. Length of scale bar = 0.5 mm. Sample courtesy of Ontario Hydro.

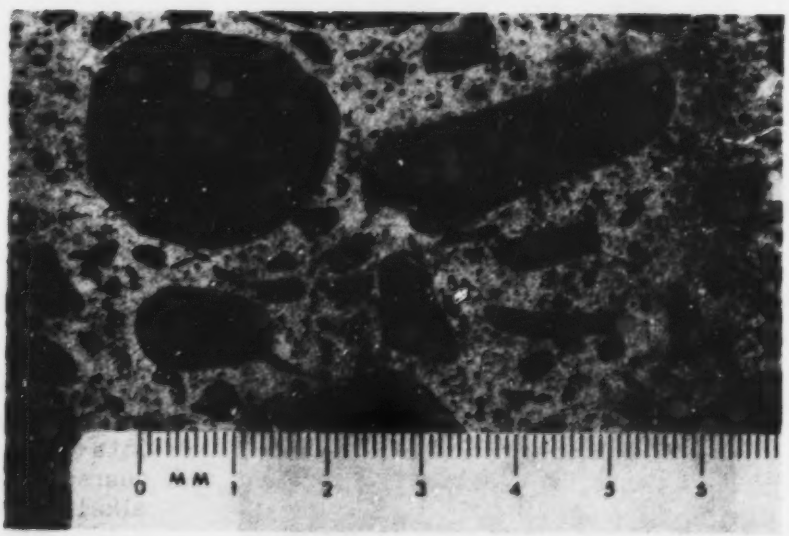

Figure 26 Alkali-silicate reaction. Lady Evelyn Lake Dam (1925). Note extensive microfractures (up to 0.3 mm) in argillite coarse aggregate. Many fractures and voids are filled with alkali-silica gel.

Figure 27

Alkali-silicate and alkali-silica reactions. Wanapitei River Bridge, Hwy. 17, built 1940, replaced 1974. Note areas of pattern cracking and major cracks due to movement caused by expansion of the concrete which contained reactive argillite, greywacke and sandstone.

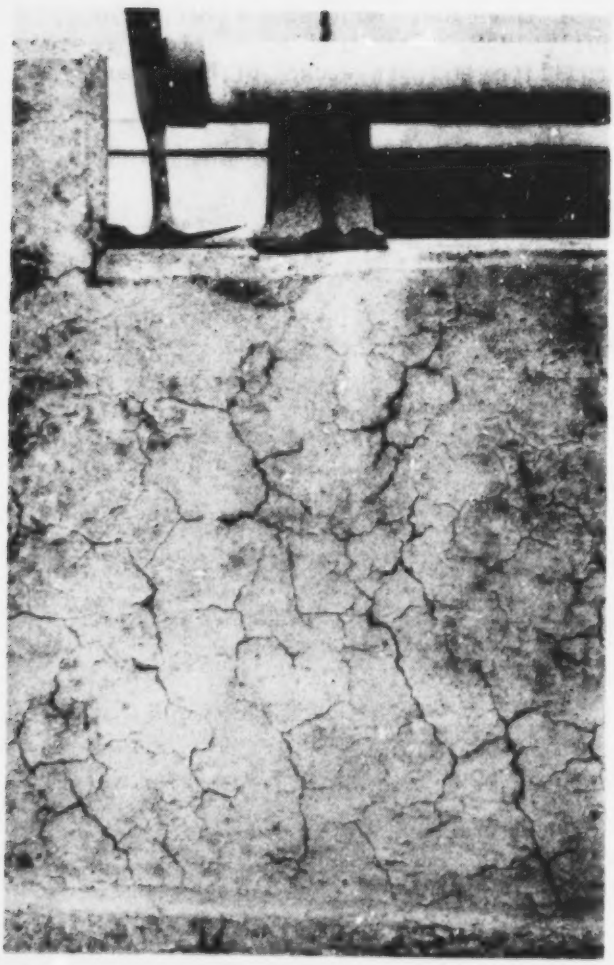

Figure 28

Alkali-silicate and alkali-silica reactions, north parapet wall, eastbound Regional Road 55 over Hwy. 17 at Liveley (Sudbury). About 70% argillite, greywacke and sandstone in the coarse aggregate. Appearance after 4 years.

Figure 29 Alkali-silicate reaction, Montreal River Bridge, Hwy.11, Latchford, built 1959. Cracking is due to a reaction with about 30% argillite and greywacke in the coarse aggregate from a local gravel source.

AGGREGATE SOURCES LIST

CONCRETE FINE AND COARSE AGGREGATE

Condition of Information

M.T.C. Contract No. _____

The coarse and fine aggregates produced from sources shown on this list can meet current OPSS physical and alkali reactivity requirements. Final approval of aggregates will be based on test results of the products according to OPSS Forms 1001 and 1002 and/or any special provisions or other requirements included in this contract.

Rock screenings from quarries and sands from natural sand and gravel deposits can meet OPSS physical and alkali reactivity requirements, unless otherwise indicated, but will require suitable processing and/or blending to meet gradation requirements.

Final approval of concrete will be dependent on satisfactory test results at the mix design stage according to OPSS Form 1350 and on previous field performance. Sources that are not shown on this list may be accepted by the Authority after they meet the appropriate physical and alkali reactivity requirements of OPSS Forms 1001 and 1002.

Page ___ of ____

F.A. - Fine Aggregate
C.A.- Coarse Aggregate
X - Acceptable
P - Pit
Q - Quarry

Mineral Aggregate Inventory Number	P or Q	Source Name and Location	F.A.	C.A.	Remarks
05-72	Q	Armbro Aggregates, Hwy. # 31, S. Gloucester	X	X	Only Beekmantown dolomitic rock, above elevation 96 metres (rock above sandstone) is acceptable. Licensed.
05-67	Q	Bertrand Concrete Products Ottawa Inc. Doncaster Road, South Gloucester (Operated by Beaver Asphalt Comp. Ltd.)		X	Only Beekmantown dolomitic rock, above elevation 89 metres (rock above sandstone) is acceptable. Licensed.
A2-139	Q	Bertrand et Freres Const. Co. Ltd., Hwy. 417, Exit 51, St. Isidore de Prescott		X	Only bedrock from 2nd lift (from approx. 5.5 m to 11.5 m) is acceptable. Licensed.
H4-16	Q	Bertrand et Freres Const. Co. Ltd., 5.5 km S.W. of L'Orignal, Highway 17		X	Only bedrock from upper part, 2nd lift (from approx. 6.1 to 12.1 m) is acceptable. Licensed.
W7-34	Q	A.L. Blair Construction Co. Ltd. 4.5 km N.W. of Crysler, Twp. of Finch		X	Only bedrock from 2nd lift (from approx. 4.5 to 12.5 m, S.W. Face and from approx. 6.0-14.0 m N.E. area of quarry) is acceptable. Licensed.
05-70	Q	Dibblee Construction Co. Ltd. Highway 31 & Rideau Road, S. Gloucester		X	Only Beekmantown dolomitic rock, above elevation 91 metres (rock above sandstone) is acceptable. Licensed.
05-05	Q	Francon (Div. of Canfarge Ltd.) Highway # 17, Orleans		X	Only bedrock from the 1st lift, between elevations 94 to 108 metres (0-14 m from ground surface) of the north quarry is acceptable. Licensed.
05-99	Q	Deschenes Const. Comp. Ltd. S.E. Corner at Klock & Pink Roads Aylmer P.Q.		X	Only bedrock from 1st lift (from approx. 0 - 7 m at S.W. Corner to approx. 0 to 9.5 m at S.E. Corner) is acceptable.
05-10 [05-94]	Q P	Dufferin Aggregates and Asphalt Div. Vanier Avenue, Aylmer P.Q.	X X	X	Only bedrock from 1st lift of quarry (from approx. 0 to 12.5 m) is acceptable for Concrete C.A. and F.A. Concrete F.A. is produced from Quarry screenings and natural sands.
05-09	P Q	Spratt Sand and Gravel Ltd. Highway 417, Exit 144, Stittsville	X	X	Only concrete F.A. produced from natural sand and/or gravel deposits is acceptable. Only concrete C.A. produced from upper 0 - 6.0 m of quarry is acceptable.
C13-78	Q	Cornwall Gravel Co. Ltd. Twp. of Cornwall, 3.7 km N.E. of Jct. Hwy's 401 and 138		X	Only bedrock from the 1st lift (from approx. 0 to 14 m) is acceptable. Licensed.
C13-29	Q	Permanent Concrete Twp. of Cornwall, 5.2 km W. of Jct. Hwy's 401 and 138		X	Bedrock from 1st lift (from approx. 0 to 15 m) is acceptable. Licensed.
B15-39	Q	Permanent Concrete Highway # 2, East of Brockville		X	Only Beekmantown dolomitic rock (above the sandstone) is acceptable.

Figure 30 Typical concrete aggregate sources list used in Ontario.

TESTING OF CONCRETE AGGREGATES FOR PHYSICAL PROPERTIES

This chapter gives a brief description of each test method and a short description of the significance of each of these tests. The test methods are described in detail in the MTC Laboratory Testing Manual*. The MTC number in the title refers to the appropriate test in the manual.

The testing of aggregates can be divided into two types:

DURABILITY TESTING
Testing of a source to predict its durability and suitability for use in concrete. This testing has to be done in one of the five MTC regional laboratories.

QUALITY ASSURANCE TESTING
Testing of a source on a routine basis to determine that the aggregate delivered on a contract meets specifications for gradation and fines content, etc. This testing is usually done in mobile or field laboratories where the results are immediately available for the construction inspector.

1. DURABILITY TESTING

Introduction

Aggregate and concrete may deteriorate by either freezing and thawing or wetting and drying. There are several tests routinely used by this Ministry to determine if aggregates are likely to deteriorate by either of these two mechanisms. They are:

- Magnesium Sulphate Soundness Test [See Dolar-Mantuani (10)]
- Los Angeles Abrasion and Impact Test [See Meininger (23)]
- Petrographic Examination [See Mielenz (24)]
- Absorption [See Mullen (25) and Dolch (11)]

The authors' names after each test refer to papers describing the application and limitations of the various test methods. These papers are recommended reading for anyone using data from these test methods.

* Available from Information Management Office, Ministry of Transportation and Communications, 1201 Wilson Avenue, Downsview, Ontario M3M 1J8.

Magnesium Sulphate Soundness Test (MTC LS-606)

This test is designed to simulate the action of freezing and thawing on aggregates. Those aggregates which are susceptible to freezing and thawing will usually breakdown and give high losses in this test. It is not infallible and the results must be interpreted by someone with a thorough knowledge of the mechanisms of deterioration of aggregates.

A weighed sample of aggregate is placed in a wire mesh basket and is submerged in a saturated solution of magnesium sulphate (Epsom salts) for 16 hours. The sample is then drained and placed in a drying oven for about 6 hours at a temperature of 110°C. This alternate wet-dry cycle is repeated five times. During each cycle the salt is absorbed into the microscopic openings in the aggregate and crystalizes during the drying period. The salt crystal growth causes internal stresses in the aggregate which will breakdown any unsound particles in the sample. After five cycles the sample is washed to remove the salt. This takes about 36 hours in a hot water bath. The sample is oven dried and regraded on the original sieves. The amount of aggregate passing the original sieve size is expressed as a percentage of the original mass of the sample.

For coarse aggregates MTC sets a specification limit of 12 percent. Only those aggregates with a loss of less than 12 percent in this test are considered suitable. There are exceptions however; aggregates with losses of up to about 20 percent have been accepted <u>if</u> they have satisfactory field performance in concrete. The limit for fine aggregates is 16 percent loss.

Los Angeles Abrasion and Impact Test (MTC LS-603)

This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported and placed.

The Los Angeles machine closely resembles a ball mill. A large closed drum rotates at 33 revolutions a minute. A steel shelf in the drum picks up the aggregate and a charge of steel balls and drops them. A 5000 g sample of graded coarse aggregate is placed in the drum and the drum is rotated for 500 revolutions. The sample is removed and screened on a 1.70 mm sieve. The amount of sample passing the sieve is expressed as a percentage of the original mass of the sample.

The maximum loss permitted by MTC is 35 percent. Some granites and gneisses found in Northern Ontario give much higher losses in this test than is warranted by their performance. In some areas if an aggregate is granitic or gneissic up to 50% loss may be permitted for use in asphaltic concrete.

This test is only done on coarse aggregate.

Petrographic Examination (MTC LS-609)

Petrographic examination is the most useful and quickest quality test. A great deal of operator experience is needed, however, to perform the test correctly.

About 200 particles of each aggregate size are examined using a stereoscopic microscope, a pen knife and a bottle of weak hydrochloric acid. The particles are separated into different groups depending on their rock type and quality. A sample may contain as many as 25 different rock types (Figure 30). Four quality categories are recognized: Good aggregate, (Factor 1), Fair aggregate (Factor 3), Poor aggregate (Factor 6) and Deleterious aggregate (Factor 10).

A Petrographic Number (P.N.) is calculated by multiplying the percentages of each group by the appropriate factor. The products are then added up to arrive at the Concrete P.N. When aggregate is used in granular base, different factors are applied because of the different conditions under which these aggregates are used.

The higher the Petrographic Number, the poorer the quality of the aggregate. For concrete paving, MTC only uses aggregates with a P.N. of 125 or less. For structural concrete the maximum allowable P.N. is 140.

The factors applied to each rock type are based on laboratory studies and in-service performance for the intended use and the prevailing conditions in Ontario. These factors may not apply under other conditions and in other areas. The factors are subject to periodic review and are changed when necessary to reflect current experience.

The Petrographic Number may be used as the sole quality assurance test provided that previous test and performance data have established the quality of the source and that any change in quality will be apparent in petrographic analysis.

This test is only normally done on coarse aggregates. In special cases, it may be done on fine aggregate.

Absorption (MTC LS-604)

The absorption test measures the pore space in aggregate particles. The larger the pore space (higher absorption), the greater the chance that the aggregate is not durable.

The absorption is determined by placing a 3000 g sample of aggregate in water for 24 hours. Then it is surface dried with a towel and weighed. The sample is then oven dried and reweighed. The dry mass is subtracted from the saturated surface dry mass and the difference expressed as a percentage of the dry mass.

Ontario Ministry of Transportation and Communications

COARSE AGGREGATE PETROGRAPHIC ANALYSIS

PIT NAME UNKNOWN LAB NO. 84-40051

DATE May 18 1985 FRACTION 19.0 - 9.5 mm ANALYST D. Hanna

TYPE NO	TYPE	MASS	%	GRANULAR & 160 mm TYPE B CORRECTION	
1	CARBONATES (hard)				
20	CARBONATES (slightly weathered)				
2	CARBONATES (sandy, hard)				
21	CARBONATES (sandy, medium hard)				
23	CARBONATES CRYSTALLINE (hard)				
3	SANDSTONE-ARKOSE (hard)	307	22.1		
22	SANDSTONE-ARKOSE (medium hard)				
4	GNEISS - SCHIST (hard)	359	25.8		
5	QUARTZITE (coarse and fine grained)	140	10.1		
6	GREYWACKE -ARGILLITE (hard)	211	15.2		
7	VOLCANIC (hard and slightly weathered)	59	4.3		
8	GRANITE - DIORITE - GABBRO	205	14.8		
9	TRAP	26	1.9		
	TOTAL GOOD AGGREGATE		94.2		
24	CARBONATES CRYSTALLINE (slightly weathered)			x 2	
40	CARBONATES (soft; slightly shaley)			x 2	
41	CARBONATES (sandy, soft and soft pitted)			x 2	
42	CARBONATES (deeply weathered)				
25	GNEISS(brittle) SCHIST (medium hard)	25	1.8	x 2	3.6
26	CHERT - CHERTY CARBONATES			x 2	
27	GRANITE - DIORITE - GABBRO (brittle)			x 2	
28	VOLCANIC (soft)			x 2	
52	ENCRUSTATION			x 2	
29	GREYWACKE - ARGILLITE (medium hard)	36	2.6	x 2	5.2
30	SANDSTONE-ARKOSE (brittle)				
	TOTAL FAIR AGGREGATE		4.4		
43	CARBONATES (shaley or clayey)				
44	CARBONATES (ochreous)				
45	CHERT - CHERTY CARBONATES (leached)			x 5	
46	SANDSTONE-ARKOSE (friable)			x 3	
48	VOLCANIC (very soft, porous)	4	0.3	x 3	0.9
49	CARBONATES CRYSTALLINE (soft)			x 3	
50	GNEISS (friable)	10	0.7	x 3	2.1
51	GRANITE - DIORITE - GABBRO (friable)			x 3	
53	CEMENTATIONS			x 3	
54	CEMENTATIONS (total)			x 3	
55	SCHIST (soft)	5	0.4	x 3	1.2
56	SILTSTONE (friable)			x 3	
	TOTAL POOR AGGREGATE		1.4		
60	OCHRE				
61	SHALE				
62	CLAY				
63	VOLCANIC OR SCHIST (decomposed)	2	0.1		
	TOTAL DELETERIOUS AGGREGATE		0.1		
	TOTALS	1389	100.1		13

% GOOD 94.2 x1 = 94.2

% FAIR 4.4 x3 = 13.2

% POOR 1.4 x6 = 8.4

% DELETERIOUS 0.1 x10 = 1.0

HOT MIX, SURF. TREAT. AND CONCRETE P.N.	116.8

EST. PERCENT CRUSHED	60
EST. PERCENT FLATS & ELONGATED	5

CORRECTED GRANULAR AND 16.0 mm TYPE B P.N.	103.8

PH-CC-343 85-06

Figure 31 Form used by MTC for calculating P.N. during petrographic examination.

MTC allows only those coarse aggregates with an absorption of less than two percent to be used in concrete. As in the Magnesium Sulphate Soundness test, there are cases where aggregate with an absorption of more than two percent is used because of its satisfactory field performance.

The absorption and relative density of fine aggregate is determined using a different test method (MTC LS-605). The results are not used for accepting or rejecting aggregate but for mix design calculations.

Organic Impurities Test (MTC LS-610)

A natural sand may be durable from a freeze-thaw point of view, however, if the sample contains an excessive amount of organic material, it is then unsuitable for concrete. The organic impurities found in sand usually consist of products of decayed vegetable matter and appear in the form of black humus or dark brown to yellowish brown loam. Most of the time this organic matter is restricted to overburden, however, occasionally it may appear in lenses or stringers in a deeper part of the deposit. Organic impurities tend to interfere with the hydration of the cement, reduce the bond strength and also affect the air entrainment. All overburden covering granular deposits containing organic impurities must be removed. If the organic matter is present throughout the deposit, washing of the aggregate may remedy the situation.

The test used to determine the amount of organic material present in concrete sand is called the Sodium Hydroxide Colorimetric Test. The test is done with a medicine bottle. The bottle is filled with a representative sample of sand to the 150 mL level. A 3% solution of sodium hydroxide is added and topped up to the 200 mL level. The sample is shaken vigorously and then left to stand for 24 hours. The colour of the solution is then compared to that of a standard colour plate which determines the amount of the organic content. The numbers 1 and 2 indicate acceptability, 3 indicates a borderline material and a need for further testing, i.e., a mortar strength test, 4 and 5 indicate a failure.

It should be noted, however, that some sands found in the Canadian Shield have been reported to cause excessive air-entrainment and low strength concrete even though they pass this test. McNaughton and Herbich (24) reported that sand found in Sault-Ste-Marie, Sudbury, Chalk River and other parts of the shield gave problems of excessive air. This resulted in low strength concrete. It should be noted that heating the aggregate to 100°C, preparatory to a concrete mix design, removes the organic material. Thus the problem of excessive air may not show up in the mix design stage. Prolonged mixing of concrete containing these aggregates will increase rather than decrease the amount of entrained air.

Doell (4) reported that mix water containing algae also increased air in concrete, resulting in reductions in compressive strength.

2. QUALITY ASSURANCE TESTING

The tests described above are not usually done in field laboratories either because of the need for specialized equipment or because of their specialized nature. The tests described below can all be easily done in field laboratories. The results of such tests as, gradation and fines content are usually needed very quickly and so are normally done in the field where immediate action may be taken if the sample does not meet the specifications.

Gradation Test (MTC LS-602)

A sample of aggregate is dried in an oven to constant mass. The material is then screened on a mechanical sieve shaker for a fixed time. The material retained on each sieve is weighed and the grading curve is calculated.

The mass of sample depends on the maximum aggregate particle size and is specified in the test manual. It is worth noting that the test method must be strictly followed and the screens should be clean and in excellent condition. If these precautions are not followed, major errors will occur.

The ability of an aggregate to meet the MTC grading requirements does not mean that workable concrete can be made with it. In a recent example, a Ready-Mix supplier in southern Ontario was unable to obtain workable concrete. There was excessive harshness, bleeding and segregation of his concrete. This poor workability was due to the use of a coarse sand. This sand, however, still met the MTC grading requirements (see Figure 32).

Fines Content Test (MTC LS-601)

A high percentage of fines on coarse aggregate is undesirable because it forms a coating on the aggregate particles and prevents a good bond with cement paste. A large number of dust particles also increase the water requirement for a given slump, thereby increasing the water/cement ratio and decreasing the strength and durability of the concrete.

This test should be done on all samples of concrete coarse aggregate submitted for testing because any attempt to visually assess the presence of fines in a stockpile, truck, bin or even a sample bag is almost impossible. The test is performed by splitting off approximately 3000 g of the oven dried coarse aggregate and washing this sample in a pan of water by agitating and decanting through a 75 um sieve. This procedure is repeated several times until the aggregate and the wash water appear totally clean. The sample is then dried to a constant mass and reweighed. The loss in mass is expressed as a percentage of the original mass.

The maximum loss allowed for crushed gravel is 1 percent while the maximum for quarried aggregate is 2 percent. The extra amount allowed for quarried aggregate is because the

nature of the fines has proven less detrimental than natural or gravel fines which often have a significant clay content.

Flat and Elongated Particle Test (MTC LS-608)

A flat or elongated particle is one which has a ratio of the longest dimension to the shortest dimension equal to or larger than 4 to 1. Those particles that are obviously cubical are separated by eye from those that appear to be flat or elongated. The doubtful pieces are measured with a set of doubled ended calipers locked in a 4:1 ratio.

MTC limits the maximum amount of flat and elongated particles to 20 percent by mass. A large number of these particles in an aggregate will result in poor workability of the mix and may reduce the strength of the concrete.

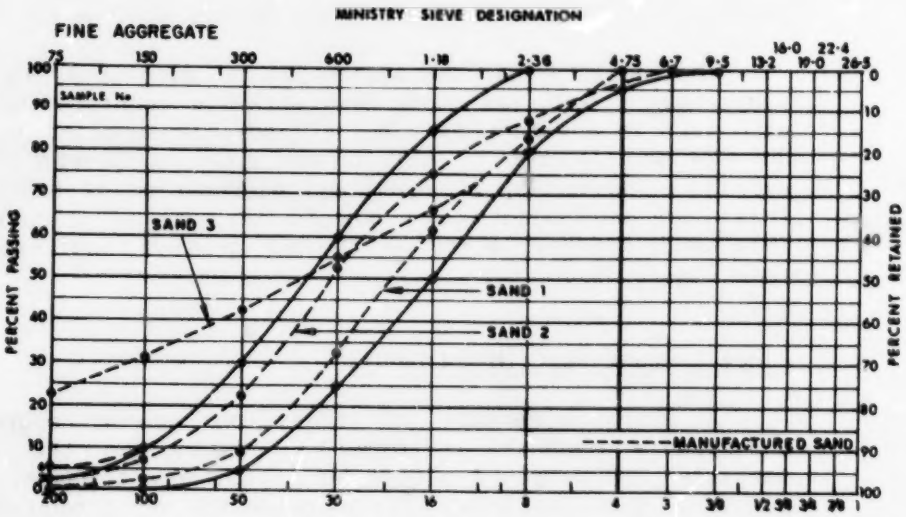

Figure 32. Sand 1 gave concrete with excessive segregation and poor workability. Sand 2 was made by adding a blending sand to No. 1 with excellent results. Sand 3 caused a high water demand, leading to a high W/C ratio with a reduction in concrete strength from 35MPa to 24MPa.

SOME SPECIFIC PROBLEM AGGREGATES

The aggregates mentioned below have been known to cause durability problems or give misleading test results. They are not necessarily restricted to the area of occurrence shown on the maps (Figure 34 and 35).

Shale (No. 5)

Shale particles when they are close to the surface of concrete will breakdown by freezing and thawing and cause conical popouts in the overlying mortar. Shales are also detrimental when used in asphalt and granular base.

Some shales are suitable for use in embankment and swamp backfills. Durability testing is necessary before they are used, see Hudec, (20) and Franklin (14).

A study, sponsored by this Ministry, of the Blenheim moraine, investigated the mechanism of breakdown of shale and ways in which it may be removed during processing to improve the quality of the final product (Holubec and DeLory, 19). Another study by the Ministry on the removal of deleterious particles (beneficiation) is that of Ingham (21).

Shale is found over much of Southern Ontario and also near Thunder Bay.

Siltstone (No. 6)

Siltstones found in gravel pits in the Caledon area, cause popouts when used in asphalt surface course. These aggregate particles do not appear to affect the performance of structural concrete.

Porous Dolomite (No. 7)

Porous dolomites are found in parts of Southwestern Ontario. They often have absorption values greater than 2 percent (MTC specification limit). Their performance in concrete is usually satisfactory. They usually have low resistance to abrasion and should not be used in asphalt surface course.

The satisfactory performance of these porous dolomites in structural concrete, despite the high absorption values shows that service records are more important than test results.

Weathered Dolomite (No. 8)

This rock, found in gravel pits and the top layers of quarries in this area, is unsuitable for use in concrete. The rock also causes severe popouts when used in asphalt surface course. See Dolar-Mantuani (5) and (8).

Gneiss (No. 9)

This is found in the Huntsville and Parry Sound areas and gives high Los Angeles Abrasion losses. These rocks give good field performance when used in asphalt pavements and, as a result, MTC specifications permit a loss of up to 50 percent for this material instead of the normal 35 percent for all others. Gneiss is found over much of the Laurentian Shield.

Chert (No. 10)

This is found from Sioux Lookout easterly to Timmins and as far south as the Ranger Lake area. This chert has been transported south from sedimentary rocks of the James Bay Lowlands by glacial action. These cherts are alkali-silica reactive and also have poor freeze-thaw durability.

Weathered Gneiss (No. 11)

Biotite (mica) gneisses found in this area give high Magnesium Sulphate Soundness test losses. Careful examination by an aggregate petrographer may show that they are suitable for use in concrete. See Dolar-Mantuani (6) and (3).

Sibley (No. 12)

These rocks with a distinctive red colour are found in the region surrounding Thunder Bay. Difficulty is found in classifying them for Petrographic Examination because their performance varies from good to extremely poor.

Brittle Granite (No. 13)

Brittle granites with some weathering of the feldspars are found in the Dryden/Ignace area of Northwestern Ontario. These rocks sometimes give high Los Angeles Abrasion test losses. Despite the high losses in this test they make perfectly durable concrete.

Carbonaceous Limestone (No. 14)

The Ottawa limestone has a characteristically dark grey colour. This dark colour is sometimes due to the presence of

carbonaceous films and partings in the limestone. Despite the dark grey shaley or clayey appearance, these limestones may be perfectly durable. This is because absorptive clay minerals are often absent. The clay minerals originally deposited at the time the limestone was formed have been changed to authigenic feldspars by moderate metamorphism. As a result the rock is stable from a freeze-thaw point of view.

Shaley Limestone (No. 15)

Shaley limestone from the Simcoe Group is often found in gravel pits to the north of Toronto. Particles of this shaley limestone will often produce popouts when close to the surface of concrete. Unless the quantity of shaley limestone is large, deep seated deterioration will not occur. Aggregate that passes all the MTC durability tests may contain particles of shaley limestone and produce popouts when used in concrete. This is a cosmetic problem, the integrity of the concrete will not be affected.

The ability of an aggregate to pass all the MTC durability tests is no guarantee that popouts will not occur from time to time.

Lithographic Limestone (No. 16)

Very fine grained, cream coloured limestones found in gravel pits and quarries in the Midland/Orillia area are unsuitable under certain conditions. These limestones are perfectly durable from a freeze-thaw point of view. When they are used in asphalt surface course and Portland cement concrete they often crack and fracture, see Koniuszy and Rogers (23). This fracturing is probably caused by a number of factors. They often have micro-fractures formed by the forces generated by blasting and crushing. However, specimens have been found to form irregular cracks and fractures as a result of thermal cycling (heating and cooling). If the number of frectures is great enough, the bond between the aggregate particle and asphalt will decrease and sometimes result in the loss of the aggregate from the road surface. These rocks are also very susceptible to polishing by vehicle tires and, as a result, are not desirable for skid resistant road surfaces.

Micaceous Diorite

A diorite quarried near Kenora has been found to have a poor bond with Portland cement. As a result, it was not possible to make 35 MPa concrete and difficulty was found in making a consistent 30 MPa concrete. The bond with cement paste

was sufficiently poor that 20 MPa concrete scaled excessively in a laboratory freeze-thaw test. The poor bond was traced to the high biotite and chlorite mica content of the rock. The mica mineral content of about 15-20 percent gave the rock a green colour and a soapy feel between the fingers.

Oxford Dolostone

Soles (33) found that a normally sound dolostone was unstable in concrete heated continually at 150°C. This dolostone from the Oxford Formation, found in quarries in the Ottawa-St. Lawrence Lowlands is perfectly durable when used at normal temperatures and has been extensively used by MTC. The cause of the deterioration is oxidation of small amounts of iron sulphide present in the rock to iron sulphate. This caused expansion and deterioration of the aggregate and consequent destruction of the concrete (See Figure 33). MTC has tested concrete prisms made with this aggregate. The prisms were stored at 150°C. An expansion of 0.45% was found after 1 year and 0.67% at 18 months.

Gypsum

Some limestone quarries in the Niagara Peninsula contain nodules of gypsum. Gypsum ($CaSO_4.2H_2O$) is a soft, white mineral, commonly used as a retarder in portland cement. Gypsum can react with the C_3A component of portland cement to cause expansion and disintegration of concrete. No cases of deterioration have been recorded due to the presence of gypsum in these aggregates. The amount of gypsum in concrete aggregate should, however, be severely restricted.

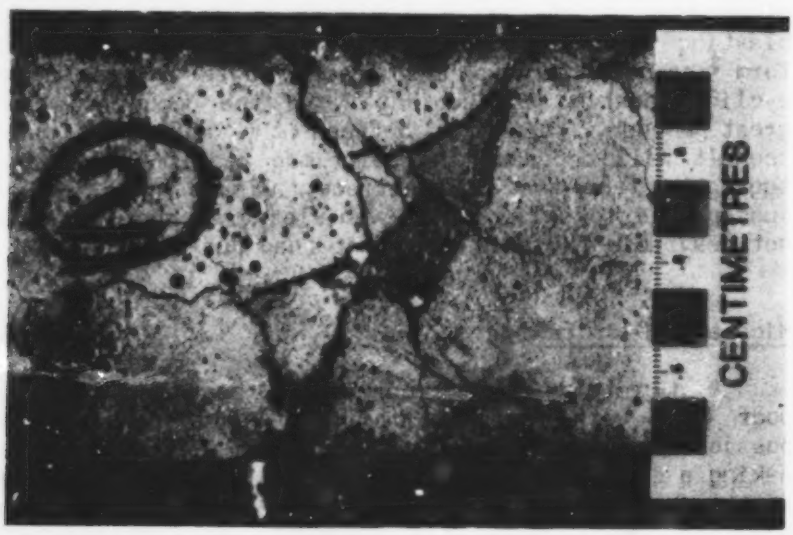

Figure 33 Oxidation of sulphides. Appearance of concrete prism made with Oxford dolostone after storage for about a year at 150°c.

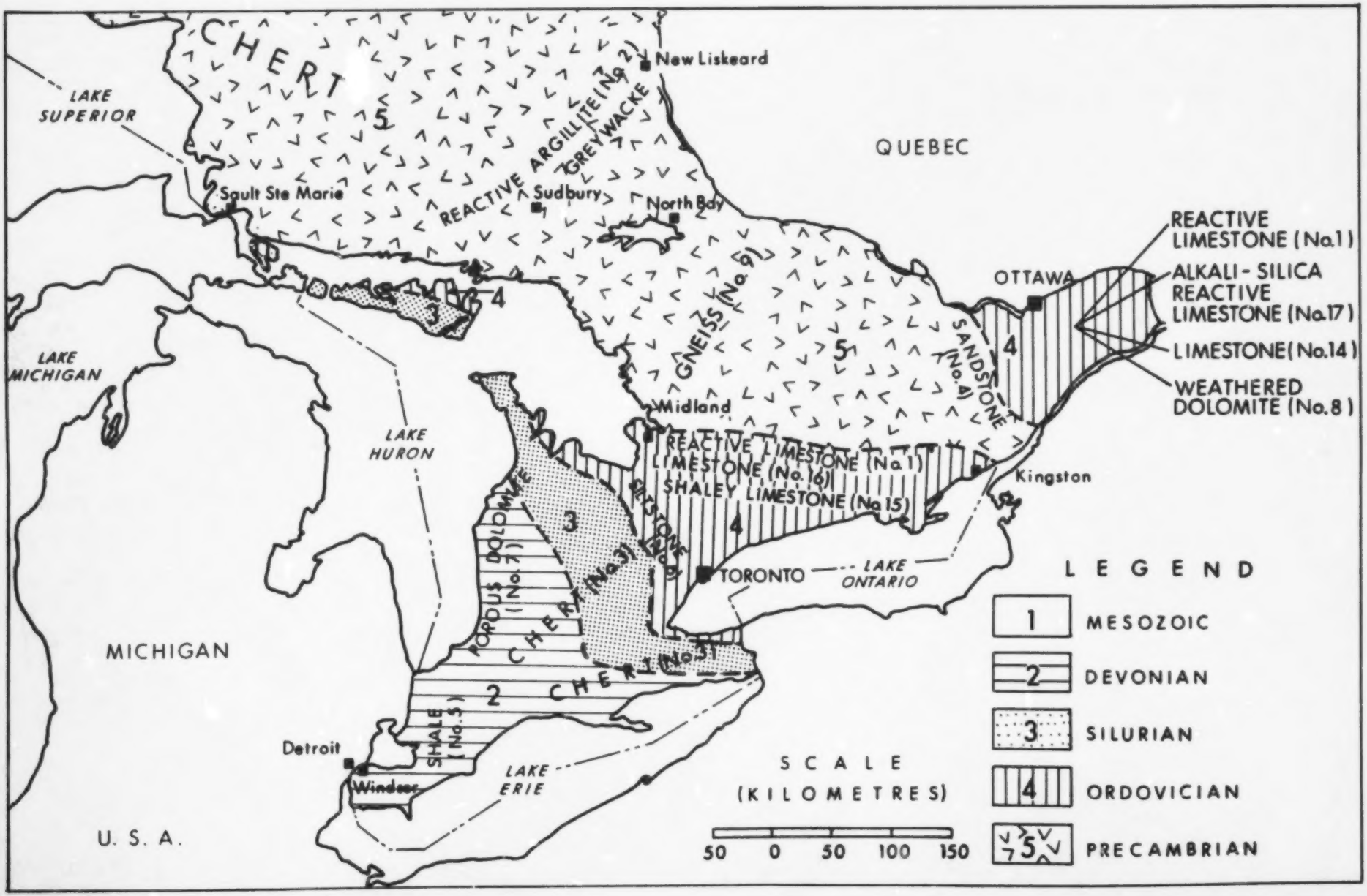
CHERT
5
REACTIVE ARGILLITE (No 2)
GREYWACKE
New Liskeard
LAKE SUPERIOR
QUEBEC
Sault Ste Marie
Sudbury
North Bay
REACTIVE LIMESTONE (No.1)
ALKALI - SILICA REACTIVE LIMESTONE (No.17)
LIMESTONE (No.14)
WEATHERED DOLOMITE (No.8)
OTTAWA
GNEISS (No 6)
SANDSTONE (No.4)
LAKE MICHIGAN
LAKE HURON
Midland
REACTIVE LIMESTONE (No.1)
LIMESTONE (No.16)
SHALEY LIMESTONE (No.15)
Kingston
TORONTO
LAKE ONTARIO
LEGEND
MESOZOIC
DEVONIAN
SILURIAN
ORDOVICIAN
PRECAMBRIAN
MICHIGAN
Detroit
Windsor
LAKE ERIE
SCALE (KILOMETRES)
50 0 50 100 150
U. S. A.

FIGURE 34

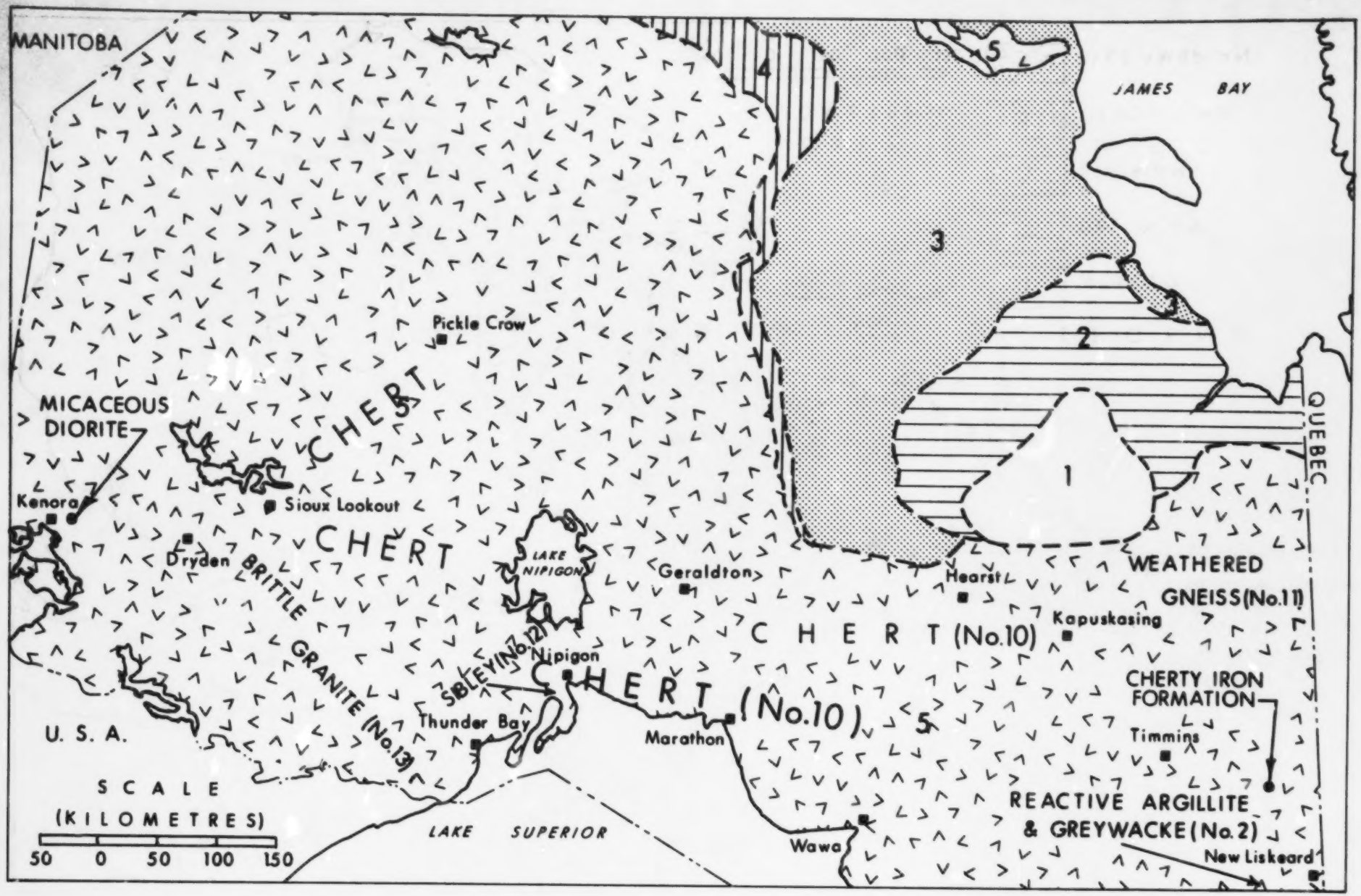
MANITOBA
JAMES BAY
QUEBEC
5
4
3
2
1
Pickle Crow
MICACEOUS DIORITE
CHERT
Kenora
Sioux Lookout
Dryden
CHERT
LAKE NIPIGON
BRITTLE GRANITE (No.13)
SIBLEY (No.12)
Geraldton
Hearst
WEATHERED GNEISS (No.11)
Kapuskasing
C H E R T (No.10)
Nipigon
CHERT (No.10)
CHERTY IRON FORMATION
Thunder Bay
Marathon
Timmins
U. S. A.
SCALE (KILOMETRES)
50 0 50 100 150
LAKE SUPERIOR
REACTIVE ARGILLITE & GREYWACKE (No.2)
Wawa
New Liskeard

FIGURE 35

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